11.1 DEVELOPMENT OF A WSR-88D BASED SNOW ACCUMULATION ALGORITHM FOR QUANTITATIVE PRECIPITATION ESTIMATES OVER SOUTHWESTERN OREGON

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1. INTRODUCTION

The Bureau of Reclamation (Reclamation) is working on a water resources project in southwestern Oregon that uses WSR-88D (Weather Surveillance Radar-1988 Doppler, also known as NEXt generation weather RADar or NEXRAD) based Quantitative Precipitation Estimates (QPE) over watersheds draining into reservoirs. Such QPEs are being used with Internet decision support tools to improve water management efficiency (e.g., the Agricultural Water Resources Decision Support system) (Hartzell et al., 2000). The accuracy of the WSR-88D Level III products (described by Crum et al., 1993) over southwestern Oregon based on the standard $Z_e = 300R^{1.4}$ default relationship with no range correction are not sufficient for Reclamation's operational needs. This default Z_e-R relationship is intended for rain and is known to be invalid for snowfall. Snow can be expected to exhibit a different relationship because of its non-spherical nature, different dielectric constant, and slower fall speeds. The QPE problem is further complicated in the west due to the mountainous terrain, the location of the Medford WSR-88D at a high elevation location from which it views ice particles during winter months, and other factors.

2. SNOW ACCUMULATION ALGORITHM

Reclamation meteorologists and programmers began development of a Snow Accumulation Algorithm (SAA) for the WSR-88D Operational Support Facility in June 1995. This project used the highest resolution Z_e data recorded called Level II, with 0.5 dBZ intervals and single range bin (1° X 1 km) spatial resolution. An overview of the SAA was presented by Super and Holroyd (1997), and the SAA development was described in detail by Super and Holroyd (1998) in their final project report.

Level II data are used as input to the Precipitation Processing System algorithm calculations associated with each WSR-88D. However, Level II observations are rarely available to non-NEXRAD agency users in real time. Consequently, Reclamation recently developed the means to use Level III reflectivities as input to a Snow Accumulation Algorithm (SAA) (Super, 1998).

Level III base reflectivity data are a NEXRAD Information Dissemination Service (NIDS) product available for the four lowest radar antenna tilts soon after each volume scan in the same range bin spatial resolution as Level II data (1° X 1 km). But Level III Z_e observations are "degraded" to 5.0 dBZ resolution in precipitation scanning mode (4.0 dBZ in clear air mode). The lower reflectivity resolution is presumably because the Level III reflectivity product is intended to be graphically displayed with up to 16 levels of color. More levels (colors) would be difficult to interpret.

During the 1998-1999 winter season, Reclamation began posting WSR-88D SAA radar snow depth and water products at URL: http://www.usbr.rsmg.gov/rsmg/ (NEXRAD Snow Algorithm Products). This URL provides access to NIDS Level III based SAA products for five WSR-88D radars located in Minnesota and the Dakotas. These experimental products continue to undergo testing and improvement in the High Plains and Upper Missouri Basin region. Five additional WSR-88D systems located in the western Dakotas and Montana will be added for the 1999-2000 winter season. This work is supported by Reclamation's Research and Technology Transfer (RTT) Program and the GEWEX Continental-Scale International Program (GCIP). (GEWEX is the acronym for the Global Energy and Water Cycle Experiment.)

The prototype SAA is intended for use with dry snow. Melting snow may provide Bright Band contamination and resulting overestimation. When considering the $Z_e = \alpha S^{\beta}$ relationship for dry snow, it was determined that $\beta = 2.0$ appeared appropriate for several locations, and a change in the β exponent of $\pm$ 0.2 has little practical significance (Super and Holroyd, 1998). This SAA uses an α of 150. Also, while a seasonal average range correction scheme is applied, the accuracy of snow estimates degrades with increasing distance (range) from each radar. The range correction factor (CF) used was: 1.04607 - 0.0029590 x r + 0.0000506 x r^2 (where r is the range from the radar.) This CF is applied only at ranges greater than 35 km.

3. PRECIPITATION OVER WESTERN OREGON

Reclamation's Bend (Oregon) Field Office requested that the Agricultural Water Resources Decision Support (AWARDS) system (Hartzell et al., 2000) be implemented in the Rogue River Basin around Medford, Oregon. For AWARDS systems east of the Continental Divide, the WSR-88D Stage III hourly Digital Precipitation Array (DPA) product produced by the National Weather Service (NWS) River Forecast Centers (RFC) works well for the high resolutions rainfall estimates used in the system. However, when trying to obtain Stage III data from the NWS Northwest RFC, it was discovered that the RFC does not produce the quality controlled Stage III products and does not have confidence in the WSR-88D precipitation estimates. Consequently, it was necessary to obtain radar-based QPE from another source.

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Reviewing WSR-88D, atmospheric sounding, and precipitation gage data for the October 1998 - May 1999 period revealed that almost all of the precipitation was from widespread, orographic precipitation events. Long-term (1961-1990) mean yearly precipitation data show the heaviest precipitation months are November-April.

Atmospheric soundings made during the 1998-1999 winter-season precipitation events were very similar to each other. Figure 1 shows an example of such a sounding (Skew-T) made at 0000Z 19 Feb. 1999. Z time is eight hours different from Pacific Standard Time (PST), so the sounding relates to 4 p.m. on 18 Feb. PST. The cloud base and top are easy to identify from the temperature-dew point traces. The freezing level was at 4,445 ft and the cloud top was near 15,340 ft.

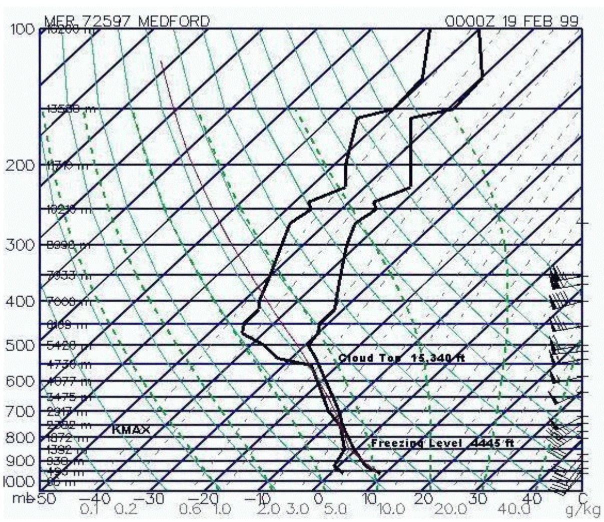

Figure 1. Example of a Medford sounding made during a precipitation period on 19 Feb. 1999, at 0000Z (or Universal Time Coordinated).

The Medford (KMAX) WSR-88D system is located on a mountain to the south of Medford (Lat. 42° 04' 52'' N, Lon. 122° 43' 02'' W) at an elevation of 7,546 ft msl (2,300 m). Figure 2 shows the 0.5 degree elevation angle radar beam at the 330 degree azimuth from KMAX. Also shown are the approximate locations of the Medford Metar (MFR), Medford Agrimet (MDFO), Sexton Summit Metar (SXT), Roseburg Municipal Metar (RBG), and Bandon Agrimet (BANO) weather stations. Since the height of the freezing level during almost all of the winter-season precipitation events was below the elevation of KMAX, it was decided to adapt the SAA for use in southwestern Oregon.

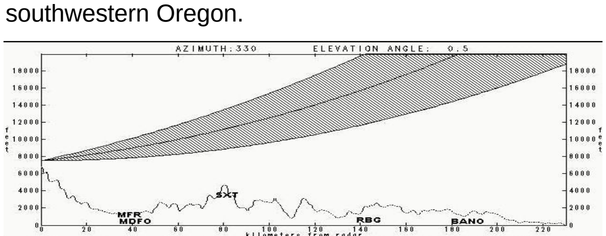

Figure 2. Mountaintop location of KMAX (7,546 ft msl) and topography under the 0.5 degree elevation angle radar beam at the 330 degree azimuth from KMAX.

4. SAA FOR SOUTHWESTERN OREGON

Reclamation's primary project area in southwest Oregon is the Rogue River Basin, which is within 100 km NW-ENE of KMAX. The Reclamation-developed SAA for the KMAX WSR-88D uses NIDS Level III reflectivity data with 4 or 5 dBZ resolution. Because of the high KMAX elevation, a value of 100 was selected for the α coefficient; the β exponent was kept at 2.0. The resulting relationship was $Z_e = 100\ R^{2.0}$. Although the SAA was used operationally during the 1998-1999 winter season, it was decided to study only those days when the Medford atmospheric sounding indicated that the height of the freezing level was below the 7,546 ft KMAX elevation, so that the lowest 0.5° radar beam could be assumed to illuminate dry snow.

Medford soundings made during periods when precipitation was being recorded at the Medford Airport had an average freezing level height of 4,980 ft and an estimated average cloud top height of 15,830 ft. At the 230 km radius KMAX radar range, the bottom of the lowest radar beam exceeds 18,000 ft. Beyond the 50 km range from KMAX, a significant portion of the precipitation was below the radar beam. Consequently, a range CF of $1.00000 - 0.00500 \times r + 0.0001428 \times r^2$ if $r > 50$ km (r is the range from KMAX) was selected and tested with the $Z_e = 100\ R^{2.0}$ relation as part of the SAA for southwestern Oregon. The SAA precipitation accumulation for each range bin beyond 50 km from KMAX was multiplied by the range CF.

Figures 3 through 6 show examples of NIDS Level III based precipitation estimates for the four different Z-R relationships and other factors used in the study. These figures show the estimated 24-hr PST precipitation accumulations for 18 Feb. 1999. Although these figures are small, the change in radar precipitation estimates between the NWS default WSR-88D settings (Figure 3) and the SAA using a range CF (Figure 6) is dramatic. In all four radar settings, precipitation was allowed to accumulate in any WSR-88D Volume Coverage Pattern (VCP) mode whenever the lowest dBZ used to calculate precipitation accumulation was exceeded.

Precipitation gage data were obtained from two Reclamation Agrimet weather stations and four Metar (ASOS) stations located within 200 km of KMAX. These six weather stations are listed in Table 1. Four of these gages usually measured rain well below the lowest radar beam which observed dry snow; however, the other two

Table 1. Precipitation gages used in study.

Precipitation Gages			From KMAX	
ID	Site Name	Elev. (ft)	Az. (deg)	Range (Km)
MDFO	Medford-Agrimet	1340	327	33.2
KMFR	Medford	1328	339	35.7
KSXT	Sexton Summit	3841	318	78.5
KLMT	Klamath Falls	4090	85	82.3
KRBG	Roseburg Muni	525	338	138.4
BANO	Bandon-Agrimet	80	309	178.8

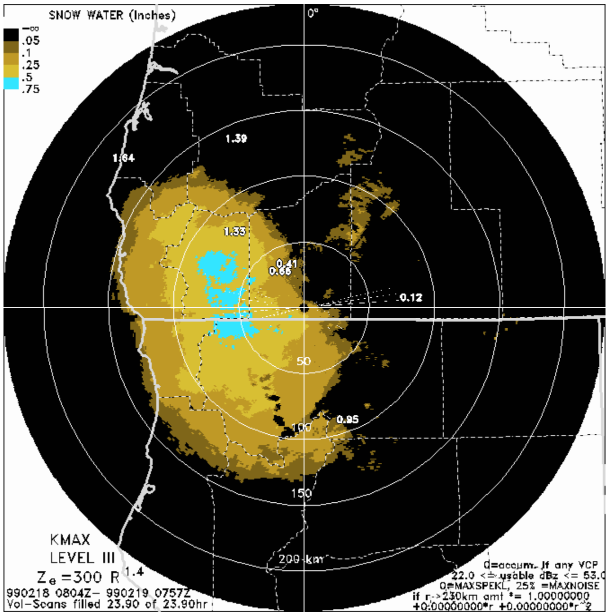

Figure 3. Default Z-R relationship, Category 2 (light precipitation) rate threshold for detection, and maximum precipitation rate allowed:

Z_e = 300 R $^{1.4}$
Precipitation Detection Threshold = 22 dBZ
Maximum Precipitation Threshold = 53 dBZ

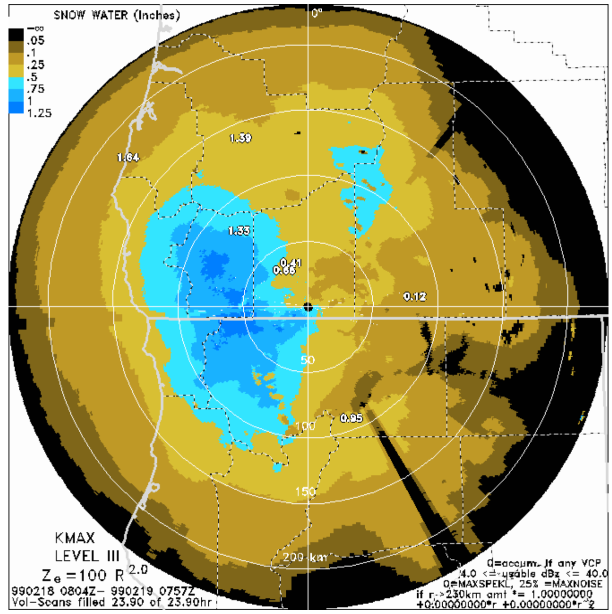

Figure 5. SAA Z-R relationship with same lowered precipitation and maximum thresholds as Figure 4:

Z_e = 100 R $^{2.0}$
Precipitation Detection Threshold = 04 dBZ
Maximum Precipitation Threshold = 40 dBZ

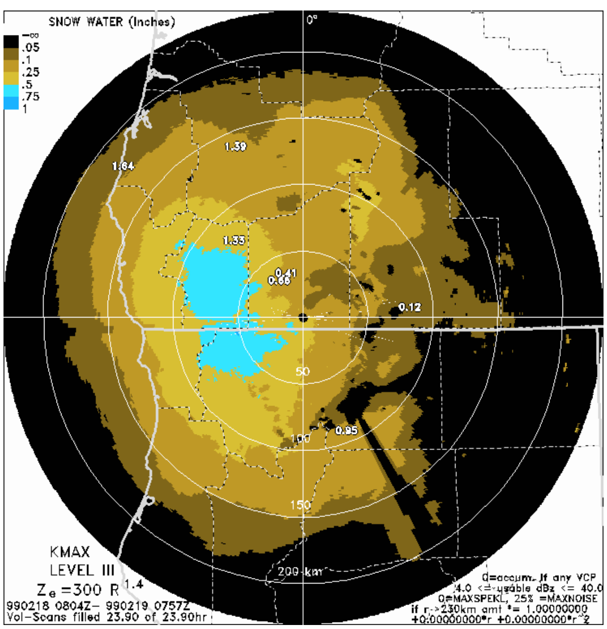

Figure 4. Default Z-R relationship with lowered precipitation and maximum rate thresholds:

Z_e = 300 R $^{1.4}$
Precipitation Detection Threshold = 04 dBZ
Maximum Precipitation Threshold = 40 dBZ

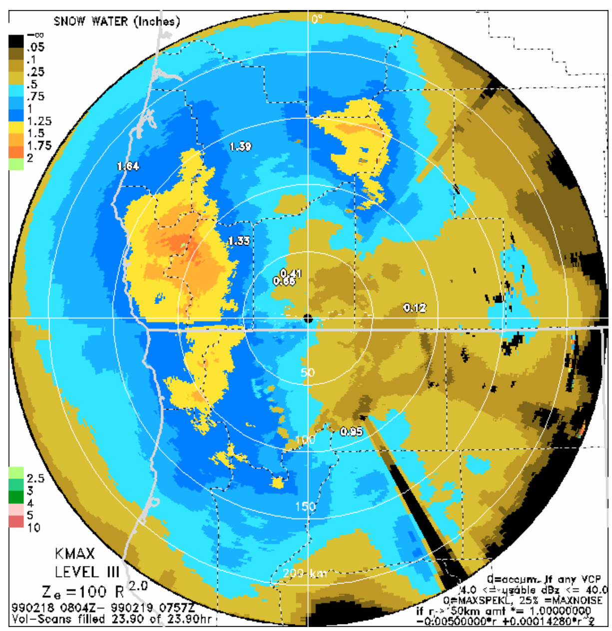

Figure 6. SAA Z-R relationship with same lowered precipitation and maximum thresholds as Figure 4, and with a range correction factor applied (if r > 50 km):

Z_e = 100 R $^{2.0}$
Precipitation Detection Threshold = 04 dBZ
Maximum Precipitation Threshold = 40 dBZ
Range CF = 1.00000 - 0.00500*r + 0.0001428*r^2

gages (KSXTand KLMT) were located at elevations where snowfall is common during the winter. The two Agrimet stations are at lower elevations and are equipped with a non-heated tipping bucket type gage. The Metar stations use heated tipping bucket gages to melt the snowfall, but such gages have been shown to be inaccurate for the measurement of snow (Groisman and Legates, 1994). Also, the gages were not equipped with Alter wind shields. Alter shields would be helpful to obtain better precipitation measurements from snowfall, but they would not entirely eliminate the wind-induced bias.

The following criteria were used in the selection of precipitation days for this study:

1. The 24-hr precipitation accumulation for the day ending at 2400 PST for both Medford gages (MDFO and KMFR) must be equal to or greater than 0.10 in.
2. The KMAX NIDS base reflectivity volume scan data for the 24-hr local time day must be complete. (NIDS data were missing for four storm days.)
3. The height of the freezing level as indicated on the Medford atmospheric soundings must be below the elevation of the Medford WSR-88D (i.e., 7,546 ft).

During the 1 October 1998 - 30 April 1999 period, there were 32 days that met all three criteria. The two Medford gages, which are located about 35 km from KMAX, were of special interest because they are within the irrigation districts using the Rogue River AWARDS system (Hartzell et al., 2000). Figure 7 shows the plot of the radar estimated versus the gage observed daily totals for the two Medford gages (32 days). The dashed line is the linear regression equation. The solid outer lines are a factor of two from the center solid line.

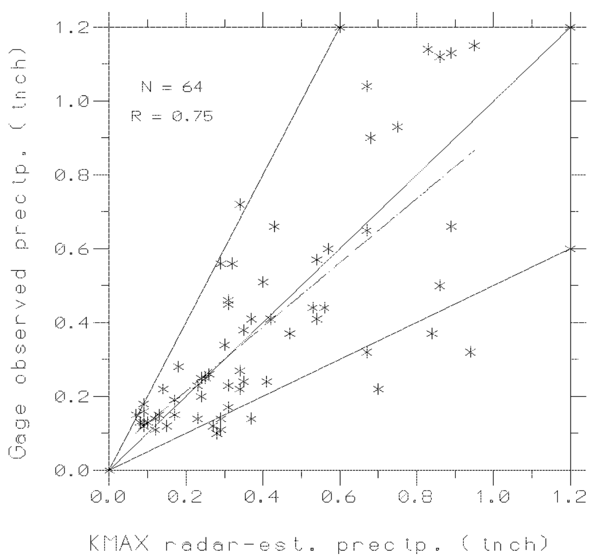

Figure 7. Plot of radar estimated vs gage observed daily precipitation totals for the two Medford gages located about 35 km from KMAX using $Z_e = 100\ R^{2.0}$.

Table 2 lists the ratios (percent) of radar estimated to gage observed precipitation for 26 storm days (22 Oct. 1998 - 27 April 1999). Data for KSXT, KLMT, and KRBG were not available for six earlier October 1998 storms.

Table 2. Ratios (%) of radar estimated to gage observed precipitation for 26 storm day totals.

Gage ID	MDFO	KMFR	KSXT	KLMT	KRBG	BANO
Range (km)	33.2	35.7	78.5	82.3	138.4	178.8
Elev (ft)	1340	1328	3841	4090	525	80
$Z_e = 300\ R^{1.4}$ min dBZ = 22	38	40	17	17	4	1
$Z_e = 300\ R^{1.4}$ min dBZ = 4	53	57	28	50	14	5
$Z_e = 100\ R^{2.0}$ min dBZ = 4	97	101	53	113	33	15
$Z_e = 100\ R^{2.0}$ min dBZ = 4 (range CF applied > 50 km)	97	101	77	171	98	68

5. FINDINGS AND CONCLUSIONS

1. A different Z_e-R relationship than $Z_e = 300\ R^{1.4}$ needs to be used for WSR-88D estimates of precipitation along western Oregon during the winter season.
2. The precipitation estimates using $Z_e = 300\ R^{1.4}$ are improved if the lowest dBZ value used to calculate precipitation is lowered (e.g., from 22 dBZ to 4 dBZ).
3. Using the Z_e-R relationship of $Z_e = 100\ R^{2.0}$ improved the precipitation estimates over $Z_e = 300\ R^{1.4}$ with a minimum 4 dBZ value algorithm. The correlation between the radar and gage estimates was 0.75, and the radar/gage ratios for the 32 storm day totals for both Medford gages were103% (99% for 26 storms).
4. Adding a range correction factor beyond 50 km to compensate for missing precipitation below the radar beam provided the best precipitation estimates over the 230 km WSR-88D coverage area.

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